QUATERNARY PALAEOENVIRONMENTAL CHANGES IN SOUTH SPAIN

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ABSTRACT

This paper presents the existing differences between the evolution of the Holocene landscape of the Southeastern and Southwestern areas of the Iberian Peninsula. Moreover, some palaeoenvironmental characteristics of OIS 4 and OIS 3 of the western Andalusia appear. The five presented sequences have been analyzed from palynological and geomorphological point of view. The obtained results show that during the Holocene no significant forest cover existed in the eastern area and that the different phases identified mainly show an alternation of shrub and steppe communities, taking place during the fifth millennium a radical transformation of the landscape and the definitive establishment of the semi-desert conditions that are registered at the present time. In the western area the evolution of the landscape is determined basically by the changes of geomorphological conditions of the coast and the marshland zones of the Guadalquivir and the Tinto-Odiel systems, registering diverse moments of increase of the aridity conditions, without remarkable changes in the vegetal landscape. Sequences obtained do not provide evidence of indicators of human intervention that might be clearly attributable to the pattern of human activities established in the area until a the two millennium ago.

KEYWORDS

Pleistocene, Holocene, Climatic Change, Pollen, South Spain

INTRODUCTION

The south of the Iberian Peninsula fundamentally presents certain characteristics due to the dryness specially in the coastal zones and inner depressions. Simultaneously, the existence of important mountains, rivers and very extensive marshes zones allows the existence of “islands” with substantial bioclimatic differences that allow the existence of different ecosystems. In the Eastern zone, the territory presents a reduced arboreal cover and has strongly been influenced by erosive processes that have made appear “semi-deserts”. Meanwhile, in the western zone, open to Atlantic influence, the Guadalquivir river and its extensive estuary and marshy zone and the Tinto-Odiel system conform extensive damp zones.

During the last years, diverse works have studied these territories from a palaeobotanical and palaeogeomorphological perspective (Menendez-Amor & Florschütz, 1964; Stevenson, 1985; Stevenson &

Moore, 1988; Stevenson *et al.*, 1992, 1999; Zazo *et al.*, 1996, 1999; Dabrio *et al.*, 2000, for the western zone; and Munuera & Carrión, 1991; Yll *et al.*, 1994; Mariscal, 1994; Burjachs & Riera, 1995; Esteban, 1995; Riera *et al.*, 1995; Carrión *et al.*, 1995, 2000; Rodriguez *et al.*, 1998; Lario *et al.*, in press.; Pantaleón-Cano, 1998; Pantaleón-Cano *et al.*, in press; Goy *et al.*, in press, for the Eastern zone).

This paper presents a new perspective on differentials processes of both zones after new cores and works. A palaeoecological approach to these differentiated territories has an important value facing the evolution with the landscape and the means and that in addition has undergone important transformations by an intense and prolonged human action.

STUDY AREA

The western area

In the western zone three new sequences have been studied. One of them in the Las Madres lagoon in the estuarine system of Tinto-Odiel and the other two in the marshland zone of the mouth of the Guadalquivir river; one in the Lucio of Mari Lopez and the other in the coast, in Marismillas, both within the limits of the National Park of Doñana (Fig. 1).

Geology

Due to the geographical proximity of Las Madres lagoon and the mixed wave-and tide-dominated Odiel-Tinto estuary, their Holocene evolution is closely related. At present, the main estuary is almost completely filled and largely separated from the open sea by an estuarine barrier that includes the spit systems of Punta Umbría, Isla Saltes, and Punta Arenilla.

The Mari López drill core was recovered from the inner parts of the present Guadalquivir estuary, that is enclosed by the spits of Doñana and La Algaida. A multidisciplinary study of the core permitted to recognise several intervals that represent diverse changing eustasy, climate, and neotectonics.

Marismillas core is located landwards of the dune ridges of Doñana spit, near the limit with the present tidal flats in the lowlands. The lowermost 35m of the core penetrated blue marlstones of Miocene age (–75 to –100 m) and fluvial conglomerates (–75 to –65m). The overlaying blue marls (–65 to –60m) record the Holocene transgressive deposits (6660 yr. BP), and non-dated transitional environments. The topmost 43m were deposited during the last 2300 yr. Sedimentary environments changed in ascending order from lacustrine to paludal, spit bar and aeolian dunes.

Climate

In the existing metereological station in the same Park, in the Palace of Doñana, the registered annual average temperature is 16,7 ºC and the precipitation is 537 mm. More to the north, in the city of Huelva, next to the Lagoon of Las Madres, the low precipitation up to 465 mm and the mean annual temperature is 16ºC.

Vegetation

The natural vegetation of Laguna de las Madres belongs to the "dry thermomediterranean" type (Rivas Martínez, 1987). The mainly formations are composed by *Olea sylvestris*, *Quercus suber*, *Juniperus oxycedrus*, *Pistacia lentiscus* y *Chamaerops humilis*. Secondary formations dominated by Ericaceae and Cistaceae shrubs are well developed. At the bottom of the depression, the hydrophilous vegetation includes Cyperaceae (*Cladium mariscus*), *Typha*, *Hydrocotyle*, *Phragmites* and ferns (*Dryopteris*, *Thelypteris*); cultivated areas of *Pinus pinea* and *Fragaria ananassa* occur in the surroundings .

The vegetation of the National Park of Doñana is dominated by Mediterranean scrub in the high zones (*Rosmarinus officinalis*, *Thymus vulgaris*, *Cistus*…) and by atlantic scrub type in the depressions, where dominate the moorlands. *Pinus Pinea*, *Quercus suber*, *Pistacia lentiscus* and *Arbutus unedo* are also present. The southern end of this protected space is occupied by a coastal dune barrier in which the vegetation is practically nonexistent. The inter-dunes depressions are covered by abundant adapted vegetation, like the *Armeria arenaria*, *Carex* and *Artemisia campestris*. In addition to the *Pinus pinea*, there are dispersed units of junipers and savins. In the zones of salt marsh, the dominant vegetation is *Salicornia* and the rush. They exist dense formations of scrub, known as "monte blanco", when the Cistaceae and Labiatae abound, and as "monte negro" in the case of xerophytic scrub vegetation with important presence of "brezos". Occupying the most internal zones, in transition between dunes and the salt marshes, they are the formation of more extensive and compact pine groves of the Park, known like Pinares de Marismillas.

The eastern area

Pollen sequences from eastern area were obtained in the coastal fringe of the province of Almería. The Antas sequence was recovered in the lower course of the river Antas, in the Vera basin. The Vera basin, with an area of 500 square km, is crossed by Almanzora, Aguas and Antas watercourses that are practically dry during most of the year. The San Rafael pollen sequence are located on the south coast of the province, at the eastern edge of the Campo de Dalías, in a formerly marshy zone. The Campo de Dalías has a low relief but is bounded to the north by the southern spurs of the Sierra de Gádor, which rises steeply to altitudes of over 2000 m above sea level.

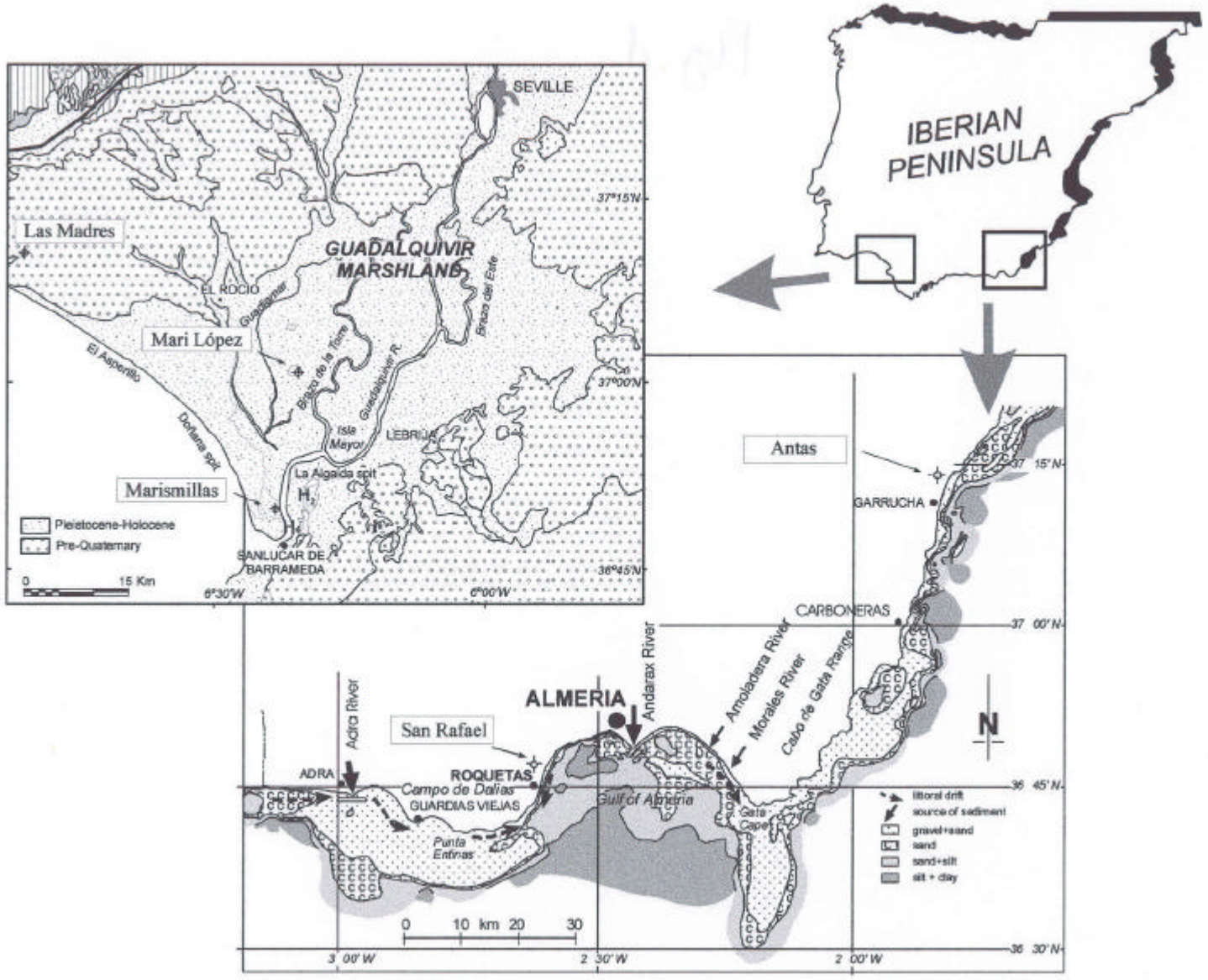

Figure 1.- Maps showing locations of the studied sites.

Geology

Geologically the areas studied are included within the structural unit constituted by the Betic mountain systems of the Iberian Peninsula. Between the mountain massifs there are Neogene and Quaternary basins, which as post-orogenic units represent the filling of the troughs with autochthonous materials spanning from the Miocene to the Quaternary.

In the Vera basin, where the Antas core was extracted, important marine sedimentary levels were deposited throughout the Miocene in such a way that the fine sediments are concentrated along the central axis of the basin whereas the coarser materials are found around the periphery. Subsequently, during the Pliocene, there were erosional phenomena that, together with the elevation of the mountain systems, caused the appearance of small coastal-lagoon basins before the final retreat of the sea. It was in this context that the rivers formed important fans that constitute the bulk of the Quaternary sediments present in the zone. As for the Campo de Dalías, where San Rafael sequence were recovered, the wide plain that constitutes it was originally a wave-cut platform during the Quaternary and was subsequently largely covered by alluvial sediments brought down from the Sierra de Gádor. The finer sediments of this alluvium, the clays and silts, are concentrated in the coastal fringe and the central and eastern sector of the plain, the coarser materials remaining in the zone of contact with the Gádor range.

Climate

The Mediterranean climate of the coast of Almería is characterized by the scarcity of annual rain, a marked seasonal distribution of the precipitation and high levels of evapotranspiration that produce a degree of aridity comparable with wide areas of North Africa. At the same time, the existence of important altitudinal gradients together with an orography that markedly compartmentalizes the area creates a variability in the general climate.

In the coastal fringe annual mean temperatures of between 18°C and 21°C are recorded. The mean annual precipitation is under 300 mm. In the depressions and watercourses of the interior the precipitation is between 250 and 300 mm, while on the eastern coast the amount is even lower, not exceeding 250 mm.

Vegetation

Local vegetation of the marsh areas where drillings were performed consists of mainly halophytic communities dominated by chenopods (*Sarcocornia fruticosa, Arthrocnemum macrostachyum, Halimione portulacoides, Suaeda vera, Atriplex glauca*), Plumbaginaceae (*Limonium caesium* among others), *Lycium intricatum, Frankenia corymbosa, Tamarix boveana, Tamarix canariensis, Inula crithmoides, Artemisia barrelieri*, etc. Beyond the domain of salt-marshes, vegetation is patched by a diversity of dense brush dominated eventually by *Maytenus senegalensis* subsp. *europaeus, Withania frutescens, Ziziphus lotus, Asparagus albus, Asparagus horridus, Rhamnus oleoides* var. *angustifolia, Chamaerops humilis, Olea europaea* var. *sylvestris, Pistacia lentiscus* and *Ephedra fragilis*. Characteristic coastal communities on rocky substrates are dominated by the endemic *Periploca angustifolia*. *Quercus*-dominated communities occur in more inland areas, especially in the subcoastal range of Sierra de Filabres and Sierra de la Alhamilla (Carrión *et al*., 2000). There has been intense debate about when this oak formations retreated in the region since vegetational processes inferred from the palaeobotanical data reveal a much more complex dynamics than the idealised phytosociological interpretation of plant succession.

METHODOLOGY

The characteristics of the presented sequences, with the corresponding dates, appear in Table 1. The complete sequence of Las Madres lagoon (LM) has been obtained using four partial sections, from the base to the top: LM 1 and LM 1bis (Russian corer), at elevation +2m asl.; LM 3 (mechanical rotation rig), at elevation +3.5m asl.; and LM 4 (the escarpment left by industrial peat extraction), at elevation +5m asl. The Mari López borehole (elevation +2.5m asl) was drilled using a 65mm rotation rig down to 65m. The Marismillas borehole (elevation +1m asl) was drilled using a 65mm rotation rig down to 100m. To recover San Rafael (elevation +3m asl) and Antas (elevation +10 m asl) cores from the varying sedimentological environments an rotation/percussion corer carried on a lorry was used down to 19m and 24m respectively. The littoral deposits in coastal plains (lagoons and marshlands) are composed basically of organic clays and silts.

The sampling interval was determined according to the sedimentation rate for each core, 10 mm section samples at intervals of 100 mm usually being taken in the case of oriental cores and the Laguna de las Madres, whereas in the other two cores of western Andalusia, the established interval was greater due to the elevated rate of sedimentation . The dry weight of the treated sediment varied between 5 and 30 g, depending on the sample's richness in pollen. Pollen was extracted from the sediment by flotation on Thoulet's solution (Goeury & Beaulieu, 1979), without acetolysis. Pollen percentages for all the palynomorphs are based on a sum of 300 to 1000 terrestrial pollen types. The pollen sum excludes taxa from local environments and hygrophilous or hydrophilous taxa, fern spores and algal remains (Birks & Birks, 1980; Moore *et al*., 1991). The pollen concentrations were calculated by the volumetric method (Loublier, 1978) and, with the exception of the case of Laguna de las

Locality	Coordinates	Material	Depth (m)	^{14}C age (yr BP)	Method	Laboratory code	Cal. age (yr BP)*
Mari López	37°01'29"N	Shell	7.3	3915 ± 50	Conventional	GX-238339	3830
	6°19'40"W	Shell	10.8	5370 ± 50	AMS	GX-23840	5680
		Shell	27.49	47.400 ± 3100	AMS	GX-23841	-
		Sapropel	39.30	31.370 ± 280	AMS	GX-25693	-
		Sapropel	40.65	> 47.000	AMS	GX-26521	-
Marismillas	36°50'9"N	Shell	38.65	2610 ± 40	AMS	GX-26386	2280
	6°22'7"W	Shell	65.30	6260 ± 40	AMS	GX-26387	6260
Las Madres 4	37°09'40"N	Peaty/ Sand	0.35	960 ± 200	Conventional	LGG-1021	910
	6°50'30"W	Peaty/ Sand	0.45	1090 ± 170	Conventional	LGG-1022	970
		Peaty/ Sand	0.60	1150 ± 190	Conventional	LGG-1023	1060
Las Madres 3		Peaty/ Sand	0.35	1570 ± 180	Conventional	LGG-1024	1420
		Peaty/ Sand	0.45	2570 ± 200	Conventional	LGG-1019	2740
		Peaty/ Sand	0.60	3410 ± 180	Conventional	LGG-1020	3680
Las Madres 1b		Peaty/ Sand	0.40	2550 ± 60	AMS	UtC-4029	2730
		Organic mud	1.05	3520 ± 60	AMS	UtC-4027	3770
		Organic mud	1.60	4450 ± 70	AMS	UtC-4030	5000
Las Madres 1		Peaty/ Sand	2.10	5480 ± 60	AMS	UtC-4023	6290
Antas	37°12'30"N	Organic	0.4	1390 ± 100	AMS	Beta-80375/	1520
	1°49'25"W	sediment				CAMS-19066	
		Org. Sed.	5.70	6280 ± 60	AMS	Beta-80376/ CAMS-19067	7160
		Org. Sed.	6.45	8210 ± 250	Conventional	Beta-92459	9100
		Org. Sed.	1025	8070 ± 90	Conventional	Beta-80377	8950
		Org. Sed.	11.15	7730 ± 100	Conventional	Beta- 92460	8650
		Org. Sed.	21.90	8690 ± 150	Conventional	Beta-65348	9800
San Rafael	36°46'25"N	Org. Sed.	2.45	1450 ± 80	Conventional	Beta-77645	1175
	2°36'5"W	Org. Sed.	6.60	4430 ± 100	Conventional	Beta-77646	5075
		Org. Sed.	13.52	7100 ± 50	Conventional	Beta-92461	7905
		Org. Sed.	15.36	9250 ± 70	AMS	Beta-92462/ AMS(Oxford)	10405
		Org. Sed.	17.00	9980 ± 60	AMS	Beta-95127/ AMS(LLNL)	11450
		Org. Sed.	18.50	16860 ± 120	AMS	Beta-92463/ AMS(Oxford)	-

Table I.- Location and ^{14}C dates of the studied cores. * (The calibrated age BP was taken as the mid-point of the 95.4% (2F).

Madres, also the method of the addition of a known quantity of *Lycopodium* spores during treatment (Stockmarr, 1971) was also used to estimate the pollen concentration. Only the main taxa are plotted on the schematics pollen diagrams (Figs. 2-6).

Radiocarbon ages of eastern sector are calibrated using version 3.0 of the CALIB program software (Stuiver and Reimer, 1993), and ages of western sector are calibrated using version 3.4 of the OxCal by C. Bronk Ramsey, 2000. A value of 402 yr was used for the reservoir effect in the Mediterranean area (Stuiver & Braziunas, 1993), and a value of 440 ± 85 yr was used in the Atlantic area after calculation in the Guadalquivir estuary (Dabrio *et al.*, 2000). AMS method was used on borehole samples, and conventional and AMS methods on Las Madres samples.

RESULTS AND DISCUSSION

The pleniglacial

A multidisciplinary study of the Mari López core permitted to recognise several intervals, with limits at depths ca. 60, 54, 39, 27, 17, 11 and 9 m, that represent diverse changing eustasy, climate, and neotectonics during the last two Glacial cycles (Zazo *et al.*, 1999). Given the problems posed by faunal reworking, two new, additional, radiocarbon data were carried out in recent times (Table 1). The results, together with geochemical and textural analyses, led to reconsideration of the proposed chronology. At present we consider that the core records sedimentation from Last Interglacial to Present.

Palynologically, the Mari Lopez core has two differentiated parts, separated by a powerful sterile package. In the lower part, between the 60 and 40 meters, has been located the pleniglacial. It corresponds at the end of isotopic stage 4 (OIS 4) and at the beginning of the OIS 3. In this section (Fig. 2, lower part) it is reflected perfectly the passage from the xeric conditions of OIS 4 where main taxa is *Pinus* and *Artemisia*, to new conditions where there is a certain increase of the hydric availability: *Artemisia* is replaced by Poaceae and Cyperaceae and spore curves settle down. In any case this hydric availability seems not much greater because, although increases the evergreen *Quercus* do not do those of deciduous type,

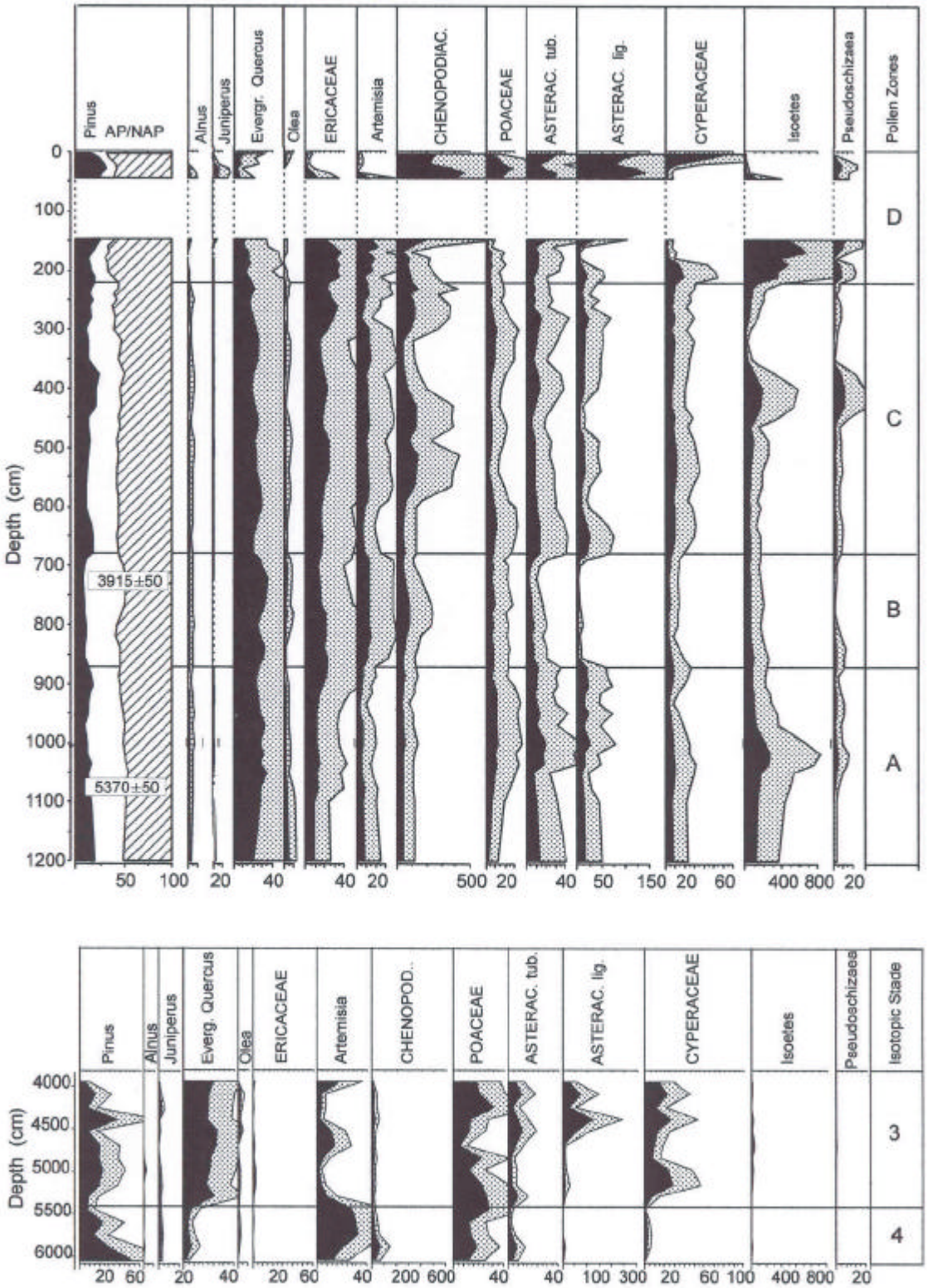

Figure 2.- Mari López schematic pollen diagram. (Upper part: Holocene; lower part: Pleniglacial).

and none of the mesophyllous taxa. The temperature does not seem to have as much importance since the rest of taxa, included those of mediterranean type, they do not have significant variations. Frenzel *et al.*(1992) establishes for Mediterranean littoral and prelittoral zones and with respect to the present values a difference of -4°C to -2°C (temperatures of the month of February) and of +200 to -100 mm of precipitation during the OIS 3. Considering the shortage of the data used for the Iberic Peninsula and the difference between the north and the south parts (Frenzel uses the same rank of variability) the variation, in the case of Andalusia, probably would be smaller.

Sequences with this chronology that allow a comparison of results do not exist in the Andalusian Atlantic zone. With respect to the eastern area, the zones of altitude, like the Cave of Carihuela (Carrión, 1992 & Carrión *et al*, 1998) or Padul (Pons & Reille, 1986, 1988) have a similar palynological behavior, whereas the littoral or prelittoral zones shows a remarkable presence of mesothermophyllous or thermophyllous taxa. The sequence of San Rafael (Fig 5), in this same paper, reflects at the end of the pleniglacial, a conditions in which are possible elevated percentages of *Olea* and mesophyllous taxa and where its abundance is greater than the beginning of the (Pantaleón-Cano *et al*, in press). Several papers suggest that Murcia's coast constituted during the last glacial phase an important zone of diversity of ligneous species, not only esclerophyllous but also deciduous, like at Perneras Cave (Carrión *et al.*, 1995), Sima de las Palomas del Cabezo Gordo and Cueva Negra del estrecho del río Quípar (Walker *et al.*, in press), or Siles (Carrión, in press). All these data support the hypothesis that many zones of coasts and of mountains of to certain altitude of the Southeast of the Peninsula were even refuge of different arboreal taxa during the last glaciation.

The Holocene in the western area

The holocene sequences corresponding to the National Park of Doñana: Mari Lopez (Fig. 2, upper part) and Marismillas (Fig. 3) show, during the middle and recent Holocene, a very similar dynamics, with some percentage differences but without noticeable changes. The low number of arboreal taxa is significant, and only *Quercus* has an significative importance. Herbaceous taxa and small shrubs are much more abundant. Excluding taxa from local character not included in the pollen sum (Asteraceae, Chenopodiaceae, Cyperaceae, spores...) only the significant ones are Poaceae, *Artemisia* and specially Ericaceae. The behavior of the different curves, including the ratio AP/NAP, that oscillates around 50%, is very stable throughout the section. In spite of general similar patterns are followed, the behavior of the samples values of Marismillas is more irregular. In Mari Lopez, where there is a greater number of analyzed samples and a greater stability of the sedimentation

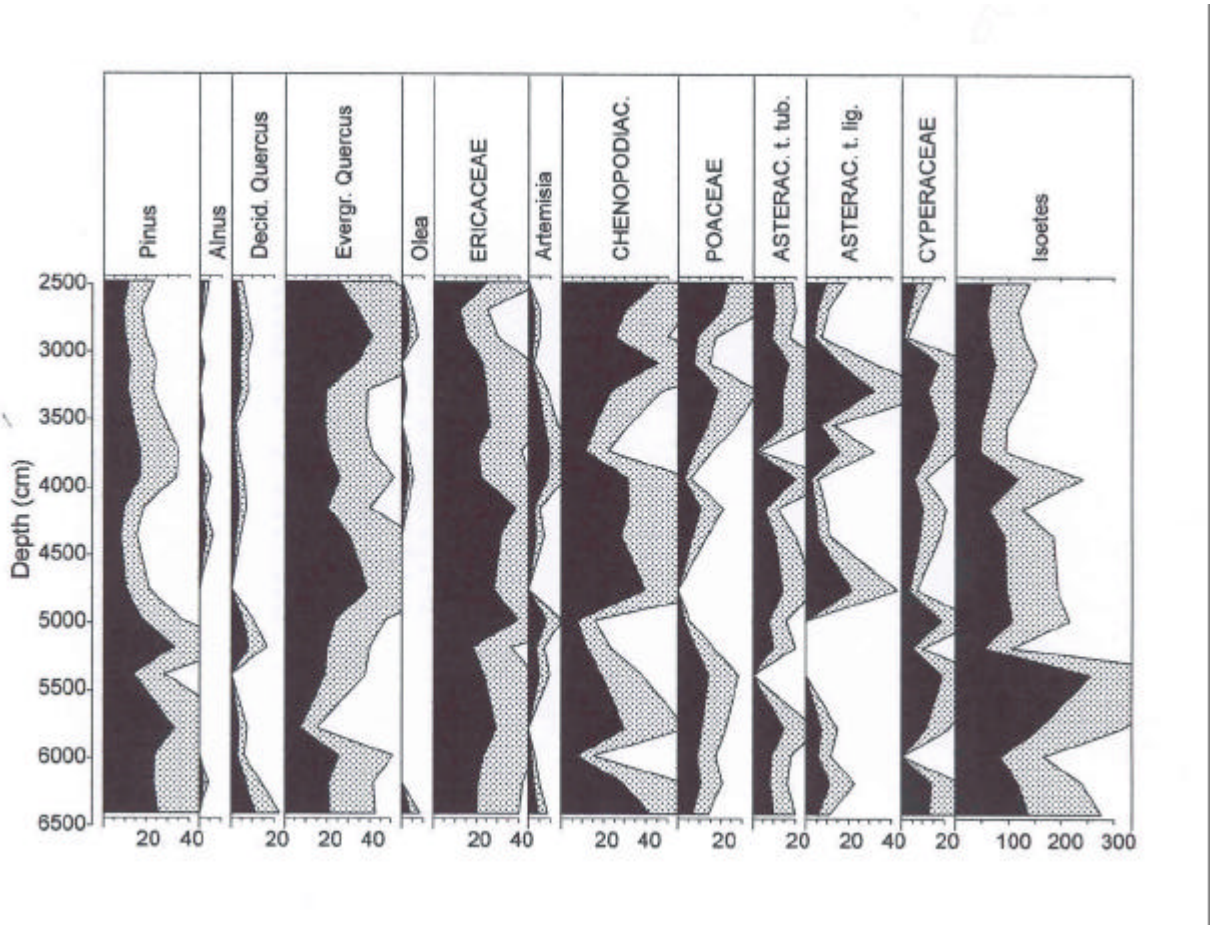

Figure 3.- Marismillas schematic pollen diagram.

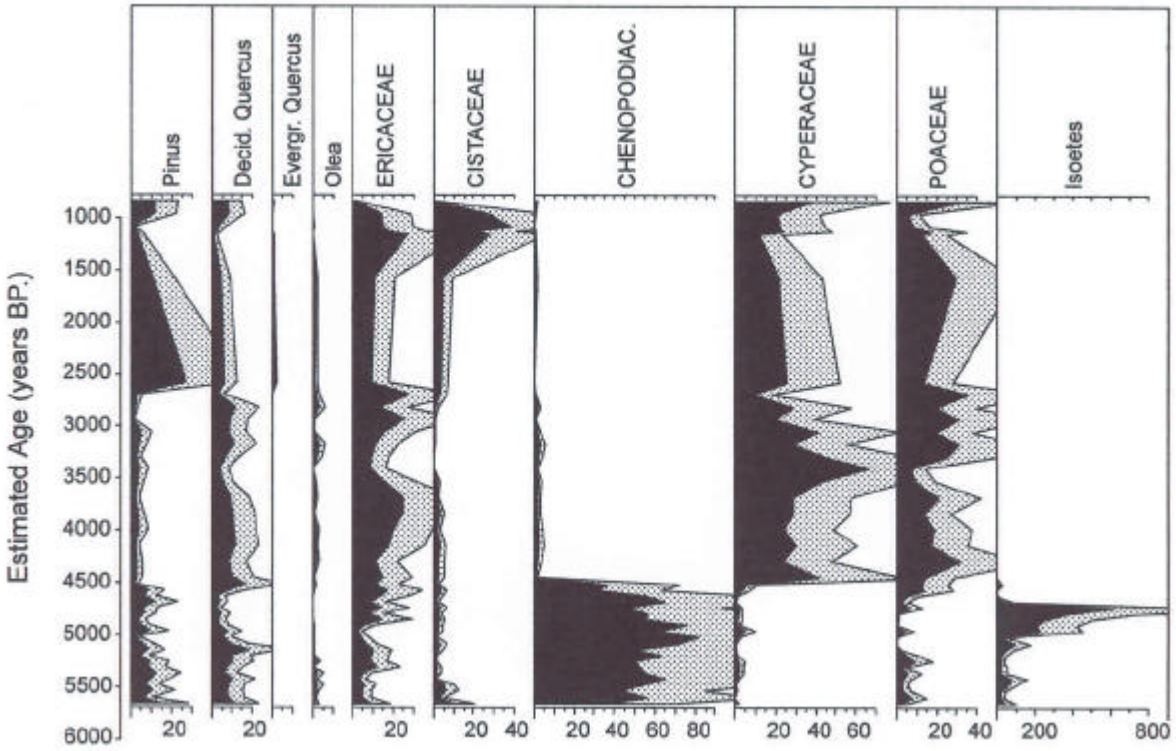

Figure 4.- Laguna de las Madres schematic pollen diagram.

processes, we can elaborate a pollinic zonation that structures better the evolution of the landscape.

The transition between zone A (lower part) and zone B is characterized by the diminution of Asteraceae and pines in relation to the increase of the values of *Artemisia*, Chenopodiaceae and, specially, of *Quercus*. After this phase, that finalizes shortly before the end of IV millenium BP, there is a situation very similar to the lower phase, although with values more elevated of *Artemisia* and Chenopodiaceae. During the phase D a formation of rafts at local level takes place (indicated by the high percentage of the spores). Immediately appear the littoral esclerophyllous maquia and the installation of conditions more similar to present with a much more hallophytic vegetation component. It seems to have produced a saltiness substrate and a water shortage, facts that can go accompanied by a modification of the coast line and a gradual drying of the marshland zones.

The occurrence of maximum flooding at 7000 BP (Goy *et al.*, 1986) is coincident with the beginning of the present highstand in southern Iberian Peninsula. Recent papers (Goy *et al.*, in press) distinguished six prograding units in the spit bar systems, called H_1: 7400-6000 BP, H_2: 5400-4200 BP, H_3: 4200-3000 BP, H_4: 2700-1900 BP, H_5: 1900-1100 BP, and H_6: 500 BP-Present. H-units are deposited during periods of high relative sea level and increased sediment input to the coast. They are bounded by large swales or erosional surfaces associated with lower sea levels and reduced input of sediment to the coast. At least since the beginning of H_2, H-units correlate well with arid periods with comparatively high sea levels, increased sediment input to the coast, increased intrusion of Atlantic Superficial Water (ASW), and stronger W-SW winds. In contrast, the boundaries of H-units correspond to periods of increased aridity with relatively-lower sea level, reduced sediment input, reduced intrusion of ASW and weaker W-SW winds.

A major change of littoral drift is observed at ca. 2.7 ka (limit H_3 - H_4), when the action of W-SW winds increased as compared with the easterlies. Changes in coastal dynamics ca. 2700 BP have been reported in other sites of southern Spain. Goy *et al.* (1998) found that Holocene aeolian accumulations began in Cabo de Gata ca. 2700 BP, under winds from the SW. Borja *et al.* (1999) showed that accumulation of Holocene aeolian dunes in the Gulf of Cadiz commenced ca. 2700 BP, under prevailing winds from the WSW.

Between 2,700 and 1,900 BP (H_4) the coastal areas experienced a dramatic change in forcing conditions, when the eastward-directed components overwhelmed the SW drift. This suggests increased south-westerly winds as compared with westerly and easterly winds. Another well-recorded erosional event took place ca. 2,300 BP. Cacho *et al.* (2001) have studied the evolution of alkenone SST in the Alborán Sea (core MD95-2043) observing a general cooling trend during the Holocene which is punctuated by periodical short-lived cooling oscillations. One of these (at 5.36 ka) coincided with the beginning of H_2, and another (at 1.38 ka) took place near the end of H_5.

In Laguna de las Madres (Fig. 4), more to the north, in the Tinto-Odiel system, the assembly of trees and shrubs taxa are also dominated by *Pinus*, *Quercus* and Ericaceae with a behavior and values very similar to those in the sequences of Doñana. Nevertheless the vegetation dynamics is clearly differentiated in two phases. The lower one, from before the date of 5480 ± 60 BP up to 4450 ± 70 BP, shows a clear domain of Chenopodiaceae and spores; while the upper zone, starting from the mentioned date, registers the substitution of Chenopodiaceae by Cyperaceae and Poaceae and the disappearance of the *Isoetes* spores. According to the arboreal and shrub levels, *Pinus* register the lowest values of the sequence while Ericaceae and *Quercus* increase clearly.

The little Las Madres incised-valley was flooded during the postglacial rise of sea level (ca. 6500 BP) forming a small marine embayment. Shortly after the maximum flooding, the bay was isolated from the sea by a beach barrier and transformed into a lagoon at 6290 yr BP (Zazo *et al.*, 1999, Borja *et al.*, 1999, Dabrio *et al.*, 2000). At ca. 4000 years BP the Las Madres coastal lagoon was transformed into a peat bog indicative of fresh water that persisted until 910 years BP. Interruption in the peat deposition seems to be related to increased development of dune systems over the lagoon.

Variations in the composition of the herbaceous community demonstrate strong modifications in the geomorphological and hydrological settings of Laguna de las Madres. At the base of the sequence, the predominance of taxa of halophytic affinity shows the opening of the depression to the ocean. Since Chenopodiaceae and Isoetes recorded similar trends, this last taxon has been ascribed to *Isoetes hystryx*, a perennial fern-like that appears at present in several habitats and also in the littoral damp meadows. The abrupt replacement of this halophytic association by a fresh-water one dominated by Cyperaceae clearly records the end of the marine influence and the definitive isolation of the depression from the Atlantic. Finally, a superior portion of the sequence, not too different from the previous one with the exception of the high percentages of *Pinus*, Ericaceae and specially *Cistus*, seems to indicate the establishment of the present conditions of the vegetation.

It is difficult to make a valid comparison with other close existing sequences. In the ordinary course of events they have been studied with non standard methodologies; it is the case of the first works made by Stevenson (Stevenson, 1985; Stevenson & Moore, 1988); with, puntual samplings (Caratini & Viguier, 1973), or without available dates (Stevenson, 1985). The only dated sequences with sufficient resolution are

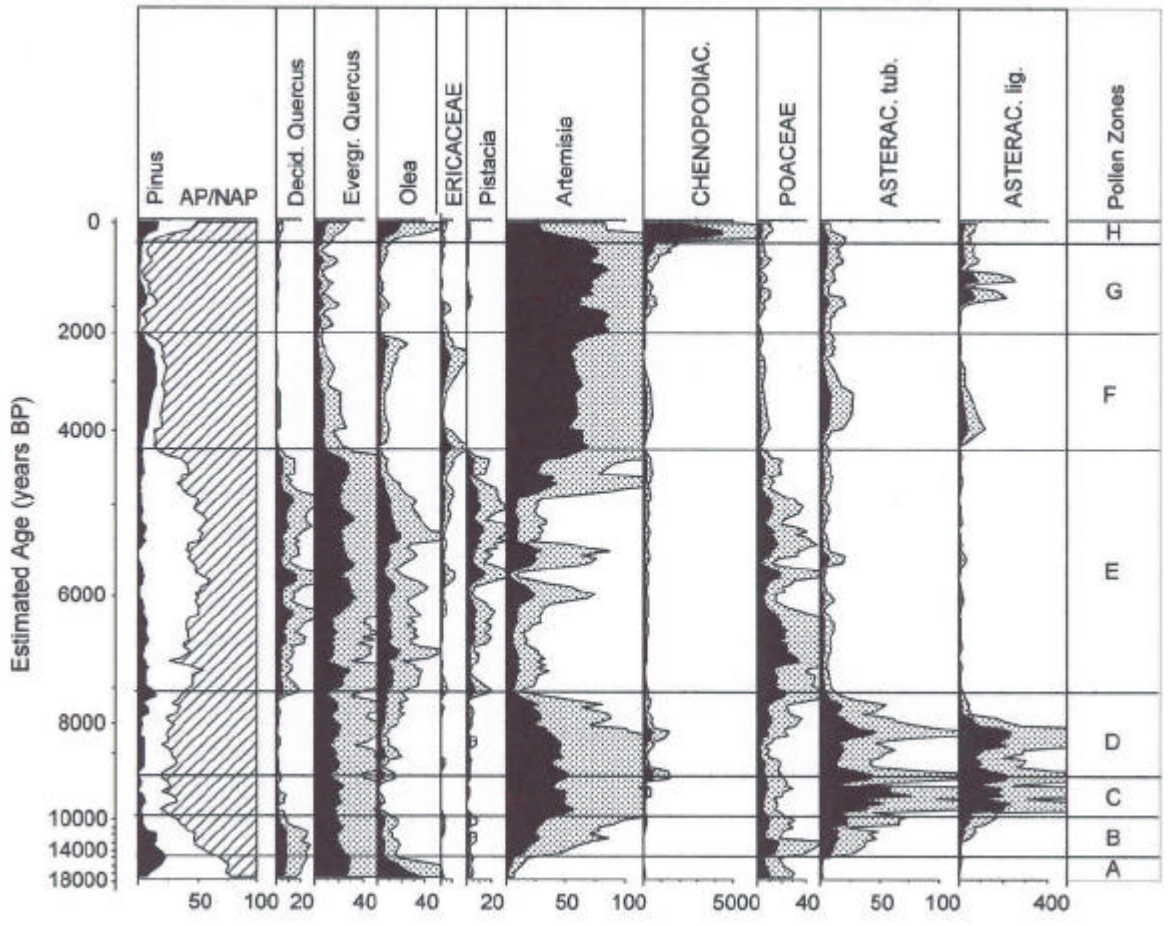

Figure 5.- San Rafael schematic pollen diagram. (Pollen zones from authors).

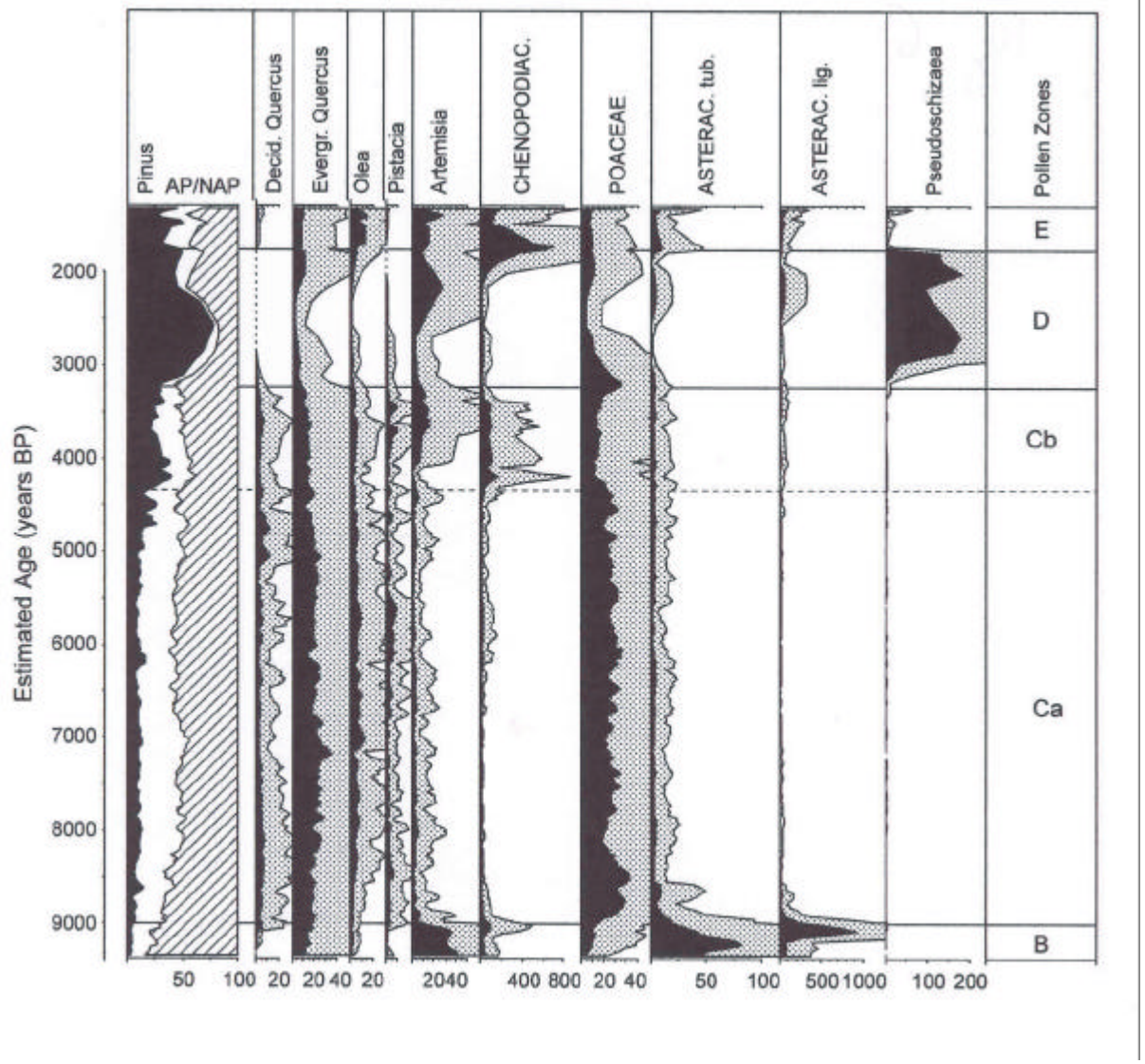

Figure 6.- Antas schematic pollen diagram. (Pollen zones from authors).

made in the Acebrón (Stevenson & Moore, 1988) and Laguna de las Madres (Menéndez-Amor & Florschütz, 1964). Although the taxonomic assembly is basically the same one, they exist remarkable differences as the importance and behavior of some taxa (e.g. the cases of *Myrtus*, *Vitis* and *Salix* in the works of Stevenson). The case of *Vitis* in Stevenson (1985) and Stevenson & Harrison (1992) is remarkable. Percentages of up to 43% in levels around 3860 BP and 4500 years BP are found. There is no reason, neither of culture nor of natural vegetation community (the two reasons have been used by the author) that explains these high percentages of pollen that is sub-represented and non well dispersed. This presence only can be due to a device or to methodological type reasons.

The Holocene in the eastern area

Considering the obtained pollen sequences and the chronology defined by the available radiocarbon dates, the two studied sedimentary sequences in the Almería coast (San Rafael and Antas, Figs 5 and 6) they can easily be correlated on the basis of the tendencies that present the diverse existing taxonomic assemblies. This way, the different pollen zones have settled down so that they allowed to correlate both sequences according to eight main pollinic assemblies that would define five great periods (Pantaleón-Cano *et al.*, in press; Yll *et al.*, 1996).

The oldest registries, between 18000 and 15000 years BP, show a pollen component mainly constituted by deciduous and evergreen *Quercus* and *Pinus*, reflecting the existence of a relatively warm and humid landscape dominated by the termophilous component, a remarkable presence of deciduous elements and, at local level, the abundant presence of hygrophilous taxa. Between 15000 and 7000 years BP the composition of the pollen registry shows the backward movement of arboreal pollen in favor of the increase of the steppic component. Simultaneously, the expansion of indicative taxa of edaphic conditions, shows an increase of the erosive processes and the reduction of plant cover of the landscape. The period between 7000 and 4500 years BP would correspond to the phase called the Holocene optimum. During this period, the steppic

component shows a great backward movement in relation to shrub component and arboreal pollen. The shrub communities would be developed widely in the lower zones whereas the forested formations with mesophilous character would extend more in the inner mountainous areas. At about 4500 years BP this situation changes radically. The components of the pollen sequences show great transformations, reflecting the establishment of essentially arid environmental conditions and the definitive installation of the steppic communities as the most characteristic element of the Almería landscape. Finally, the sectors corresponding to the most recent times invest this tendency since a recovery of the pollen concentrations is estimated by the increase of taxa that like *Artemisia* and Chenopodiaceae. This phenomenon reflects the importance of the steppic communities. Likewise, during this period, the great presence of Chenopodiaceae would be related to the formation of the halophilous coastal cords that exist at the moment in the studied zones. A progressive increase of the environmental xericity and human interventions on landscape are detected

Pollen data in the coast of Almería indicate a sudden change of the vegetal cover. The climate evolved from humid to steppe conditions ca. 5,400 cal BP (Pantaleón-Cano *et al.*, 1996; Jalut *et al.*, 2000; Yll *et al.*, 1994), . This phenomenon coincides with the beginning of H_2. From this time onwards, Jalut *et al.* (2000) distinguished four arid phases separated by shorter periods with less aridity. In our opinion, the more arid episodes represent reduced sediment inputs (and lower relative sea-levels) at the boundaries of H-units, i.e., they are short periods of increased aridity inside the general arid trend recorded in the Western Mediterranean since 4.5 ka. We suggest that the forcing factor behind these changes is the increased persistence of westerly winds during the relatively less-arid phases, that contributes to magnify the incursion of SAW into the Mediterranean and promote local rises of sea level in southern Spain, with SST relatively high. In contrast, less effective westerly winds during the shorter-lived, more-arid phases reduce the incursion of SAW, and sea level remains essentially lower, with cooler SST. Thus, changes in the flux of Atlantic superficial waters into the Mediterranean Sea and relative strength of the W/SW winds account for the recorded oscillations of relative sea level.

The regularity of progradation in Roquetas (Goy *et al*, in press) suggests a decadal periodicity for the deposition of a beach-ridge and the adjacent swale that we suggest is related with variations of solar activity and with fluctuations of the North Atlantic Oscillation (NAO) index. The duration of H units suggests a quasi-millennial periodicity of the occurrence of short periods of increased aridity that seem to coincide with the short cold events in the North Atlantic and, in some cases, with the SST events recorded by Cacho *et al.* (2001) off the coast of Almería.

CONCLUSIONS

From the available data it can be considered that the Southeastern sector of the Iberian Peninsula would be characterized by the establishment of shrubs communities dominated by wild olive. These formations would constitute the climacic vegetation of the area from the end of the last glacial period. In this sense, it seems evident that certain zones have acted as refuges of *Olea* and others species during the coldest periods of the last glacial period. The arrival of more favorable climatic conditions permitted the expansion of these taxa.. The most characteristic trend related to the evolution of the vegetation of this area is determined by the continued alternation between the steppic and shrubs communities. This fact is the determinant element of the vegetation dynamics from this zone and does not show fundamental differences with similar episodes registered during the Lateglacial and the Holocene.

Nevertheless, in the western area, a continuous presence of esclerohyllous littoral maquis is detected during all the sequence between the middle Holocene and the present time. This evolution is only altered by the change of local vegetation caused by marine fluctuations and the formation of dune barriers. The non-existence of alternative sequences previous to the middle Holocene prevents to know the antiquity sclerophyllous maquis in this zone.

The most radical change in the landscape is detected at about 5000 years BP in the Almería zone, where a dramatic deforestation of the territory accompanied by intense erosive processes and the establishment of steppic formations is observed. This last transformation would mark the beginning of the establishment of the semi-arid conditions that characterize these territories at present. In this sense, the pollinic evidences do not allow determine the human activities as the cause of this process. The anthropic action probably would only constitute one more variable, of low intensity, in the transformation of the plant landscape. Nevertheless, in the western zones, this abrupt transformation does not occur, but it is chronologically coincident with the transformations of the littoral conditions detected in Las Madres towards 4450 years BP.

None of the two areas registers influences direct antrópicas in the change of the vegetation before the 2000 years BP (to exception of the punctual presence of some taxon like Vitis), of what happens strongly in other areas antropizadas of the Next East. Possibly this is due to the control of human groups on the landscape and also to the own vegetation nature (sclerophyllous maquis) that has the capacity of recovering its biomass and its pollen production much more quickly that other types of vegetation.

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